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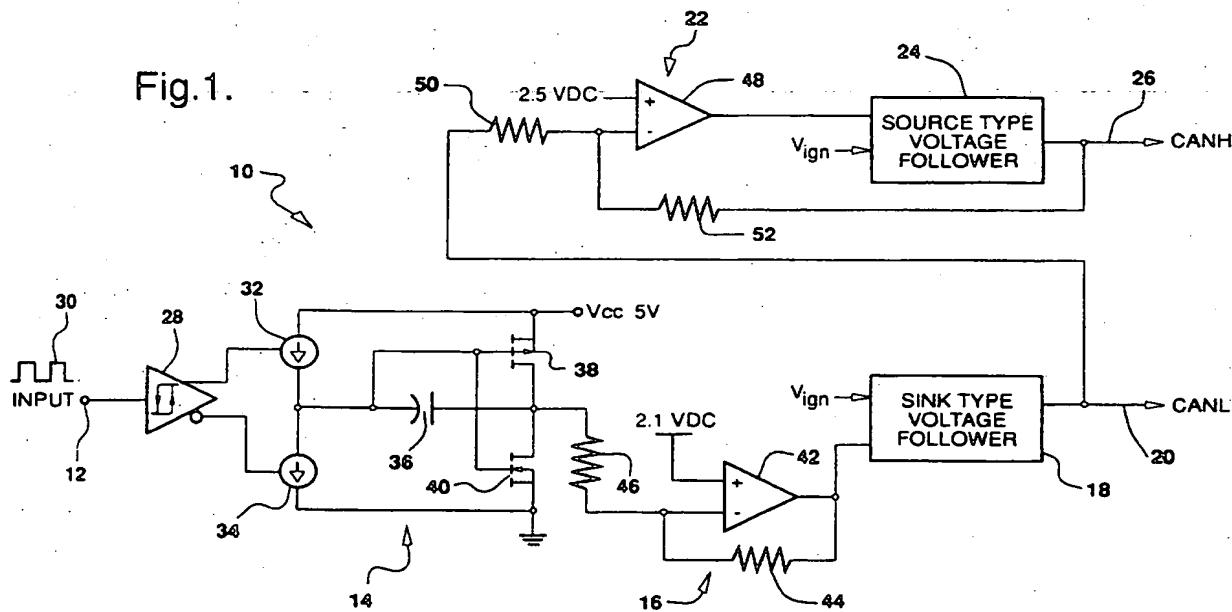
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### (54) Differential data bus transmitter

(57) A transmitter for a differential serial data communication bus incorporating the CAN format includes features for minimizing radiated emissions. The transmitter includes a second order input filter for establishing a slew rate of pulses edges and for rounding corners, a first amplifier for attenuating and level shifting the fil-

tered input to produce a first bus output, and a second amplifier coupled to the first bus output for producing a second bus output mirroring the first. The second amplifier has a high unity gain frequency and a closed loop configuration, both for minimizing phase differential of the two outputs.

Fig.1.



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DescriptionTechnical Field

This invention relates to differential serial data communication and particularly to a data bus transmitter for producing balanced phase signals.

Background of the Invention

Data communication in automotive vehicles sometimes takes the form of a controller area network (CAN) which was developed for factory operations. The CAN bus is a differential serial data communication bus using a twisted pair of lines respectively carrying high signal (CANH) and a low signal (CANL). Data is self synchronizing because of its variable pulse width protocol. The bus has two states: a recessive bit where there is a 0 VDC differential between CANH and CANL, and a dominant bit where there is a 2 VDC differential. The CAN International Standard (ISO 11898) has provisions for only controlled slew rates for both outputs. There are no phasing requirements for CANH and CANL with respect to each other.

Although CAN is useful for vehicle applications it produces an objectionable level of radiated emissions. To minimize radiated emissions during high speed transmissions, the phase of the signals must be kept as close to zero as possible, i.e. CANH+CANL equal a constant DC voltage.

Summary of the Invention

It is therefore an object of the invention to minimize radiated emissions in a differential serial data bus. Another object in such a bus is for transmission apparatus to produce differential signals substantially in phase.

A data transmitter has a wave-shaping filter at its input which establishes a slew rate of the data pulses and also smoothes the transitions at pulse corners. A level shifting and attenuating amplifier offsets the signal to a reference voltage to produce a first CAN voltage, and an inverting unity gain amplifier with high bandwidth and responsive to the first CAN voltage produces a second CAN voltage at the reference voltage and which mirrors the first CAN voltage. Due to the high bandwidth the second CAN voltage can maintain zero phase with the first CAN voltage. To further assist the zero phase of the signals, the second CAN voltage is fed back to the inverting unity gain amplifier.

Brief Description of the Drawings

The above and other advantages of the invention will become more apparent from the following description taken in conjunction with the accompanying drawings wherein like references refer to like parts and wherein:

Figure 1 is a schematic diagram of a data bus transmitter according to the invention;

Figures 2A and 2B are waveforms produced by the circuit of Figure 1 depicting bus signals both separately and summed;

Figure 3 is a graph representing a frequency spectrum of radiated emissions resulting from the outputs of the circuit of Figure 1;

Figures 4A and 4B are waveforms produced by a circuit lacking the inventive features of Figure 1 depicting bus signals both separately and summed; and

Figure 5 is a graph representing a frequency spectrum of radiated emissions resulting from the waveforms of Figures 4A and 4B.

Description of the Preferred Embodiment

Referring to Figure 1, a transmitter 10 for a CAN differential serial data communication bus has an input terminal 12 connected to a waveshaping filter 14 which provides filtered pulses to a first amplifier 16. A sink type voltage follower 18 responsive to the amplifier output produces an output signal CANL on a bus line 20. A second amplifier 22 has its inverting input connected to the bus line 20 to produce an inverted form or mirror of the signal CANL. This second amplifier signal is fed to a source type voltage follower 24 which produces the signal CANH on bus line 26. The signal CANH is fed back to the input of the second amplifier. The first and second amplifiers are biased so that they both yield the same output voltage, preferably 2.5v, when the input signal is zero, and they symmetrically diverge from the 2.5v reference level for a higher voltage signal.

The waveshaping filter 14 has a comparator 28 with hysteresis as the input element and receives a square wave data pulse 30. The comparator is set to switch to one state when its input goes above 2 volts and to switch to the other state when the input goes below 0.8 volt. A noninverted comparator output is coupled to a constant current source 32 and an inverted output is coupled to a constant current sink 34 so that those elements 32 and 34 conduct alternately according to the state of the input signal. The current source 32 and sink 34 are serially coupled between a 5 volt supply  $V_{cc}$  and ground. Their junction is connected to one side of a capacitor 36, the other side being connected to the filter output. The junction is also connected to the gates of MOSFETs 38 and 40. The FET 38 is a P-channel device, its source connected to  $V_{cc}$  and its drain connected to the filter output. The FET 40 is an N-channel device having its source connected to the filter output and its drain is coupled to ground.

In operation, the input pulse causes the comparator 55 to switch on and off to correspondingly turn the current source 32 and sink 34 alternatively on and off to charge and discharge the capacitor 36 which affects the conduction of the MOSFETs 38 and 40. The slew rate of

the filter output is fixed by the capacitor and the current limits of the current source and sink, and second order filtering at the extremes of the voltage swings effects smooth transition of the pulse edges with the maxima and minima of the waveform. The overall result is a two-stage filtering which establishes fixed slew rates for rising and falling pulse edges and rounded corners at the transition points of edges and horizontal portions of the wave shape.

The first amplifier 16 is a level shifting and attenuating amplifier including an operational amplifier 42 with its non-inverting input connected to 2.1v and its inverting input connected to its output through a feedback resistor 44 and to the filter output through an input resistor 46 having a value 5 times the value of resistor 44. These values afford an output of 2.5v when the filtered input is ground and about 1.5v when the input is at  $V_{cc}$  but following the shape of the filtered signal. The sink type voltage follower 18 is a unity-gain amplifier which replicates the amplifier output onto the bus line 20 to produce the low signal CANL.

The second amplifier 22 comprises an operational amplifier 48 having its non-inverting input connected to a 2.5v reference and its inverting input coupled through an input resistor 50 to the line 20 and through a feedback resistor 52 to the line 26. The second amplifier produces a mirror of the CANL signal which is applied to the line 26 by the voltage follower 24 which is another unity gain amplifier. The CANH signal varies between 2.5v and about 3.5v.

The unity gain frequency of operational amplifier 42 should be in the 2 to 5MHz range. The unity gain frequency of the operational amplifier 48 must be as high as possible to minimize CANH to CANL phase delay. A unity gain frequency of 70MHz has been found to be suitable to greatly enhance the ability of amplifier 48 to follow the CANL waveform. Any phase delay is further minimized by the closed loop from CANL back to the operational amplifier 48 input.

Three features of the transmitter circuit contribute to the waveforms and small phase difference of the CAN signal which in turn result in low radiated emissions. The features are the waveshaping filter 14 with second order filtering for rounding the corners of the waveform, the high unity gain frequency of the second amplifier, and the closed loop design of the second amplifier to minimize the phase difference. In combination, these three features yield waveforms shown in Figures 2A, 2B and 3. Figure 2A shows the signals CANL and CANH with rounded corners and Figure 2B shows the sum of CANL and CANH which is a nearly constant voltage just below 5v and has only a little ripple. The radiated emissions resulting from this circuit is represented by the frequency spectrum of Figure 3. There the maximum voltage is about 25 $\mu$ v. In contrast, a similar circuit having a slew rate control only without second order filtering, using 3MHz operational amplifiers, and an open loop second amplifier configuration yields the waveforms shown in

Figures 4A, 4B and 5. Figure 4A shows the sharp corners of the signals CANL and CANH, and Figure 4B shows the large signal discontinuities in the sum of CANL and CANH. The radiated emissions shown in Figure 5 reveals several voltage spikes exceeding 1mv. The overall measure of radiated emissions shows a reduction of 40 dBm resulting from the three circuit improvements.

It will thus be recognized that by optimizing the transmitter circuit operation that CAN bus systems can be applied to vehicles and still comport with strict standard for radiated emissions. It is further apparent that due to the simplicity of the circuit configuration, the great improvement in performance achieved by the invention is achievable with minimal cost increment, if any.

### Claims

1. A transmitter for a differential serial data communication bus comprising:
  - a data input;
  - first and second outputs;
  - a filter connected to the input for generating a filtered input signal;
  - first amplifier means coupled to the filter and the first output for level shifting and attenuating the filtered input signal to produce a first output signal; and
  - second amplifier means coupled to the second output and having an input coupled to the first output for inverting the first output signal to produce a second output signal, the second amplifier means having a sufficiently high unity gain frequency to minimize any phase difference between the first and second output signals.
2. The invention as defined in claim 1 wherein the filter comprises waveshaping means for smoothing out slew rate transitions, thereby attenuating radiated emissions.
3. The invention as defined in claim 1 wherein the second output is coupled to the input of the second amplifier means to reference the second output signal to the first output signal.
4. A transmitter for a differential serial data communication bus having first and second lines comprising:
  - a data input for receiving an input signal;
  - a first amplifier coupled to the data input for producing a first output signal;
  - means for coupling the first output signal to the first line;
  - a second amplifier having an inverting input coupled to the first output signal for producing

a second output signal which mirrors the first output signal; and means for coupling the second output signal to the second line.

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5. The invention as defined in claim 4 including:

feedback means connecting the second line to the inverting input; and the second amplifier having a sufficiently high unity gain frequency to minimize any phase difference between the first and second output signals.

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6. The invention as defined in claim 4 wherein:

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the first amplifier including means for producing the first output signal by attenuating the input signal and shifting to a reference voltage; and the second amplifier references the second output signal to the reference voltage.

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7. The invention as defined in claim 4 wherein:

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the first amplifier is coupled to the data input by a filter for imposing a slew rate on the input signal and including waveshaping means having second order filtering for smoothing out slew rate transitions, thereby attenuating radiated emissions.

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Fig. 1.

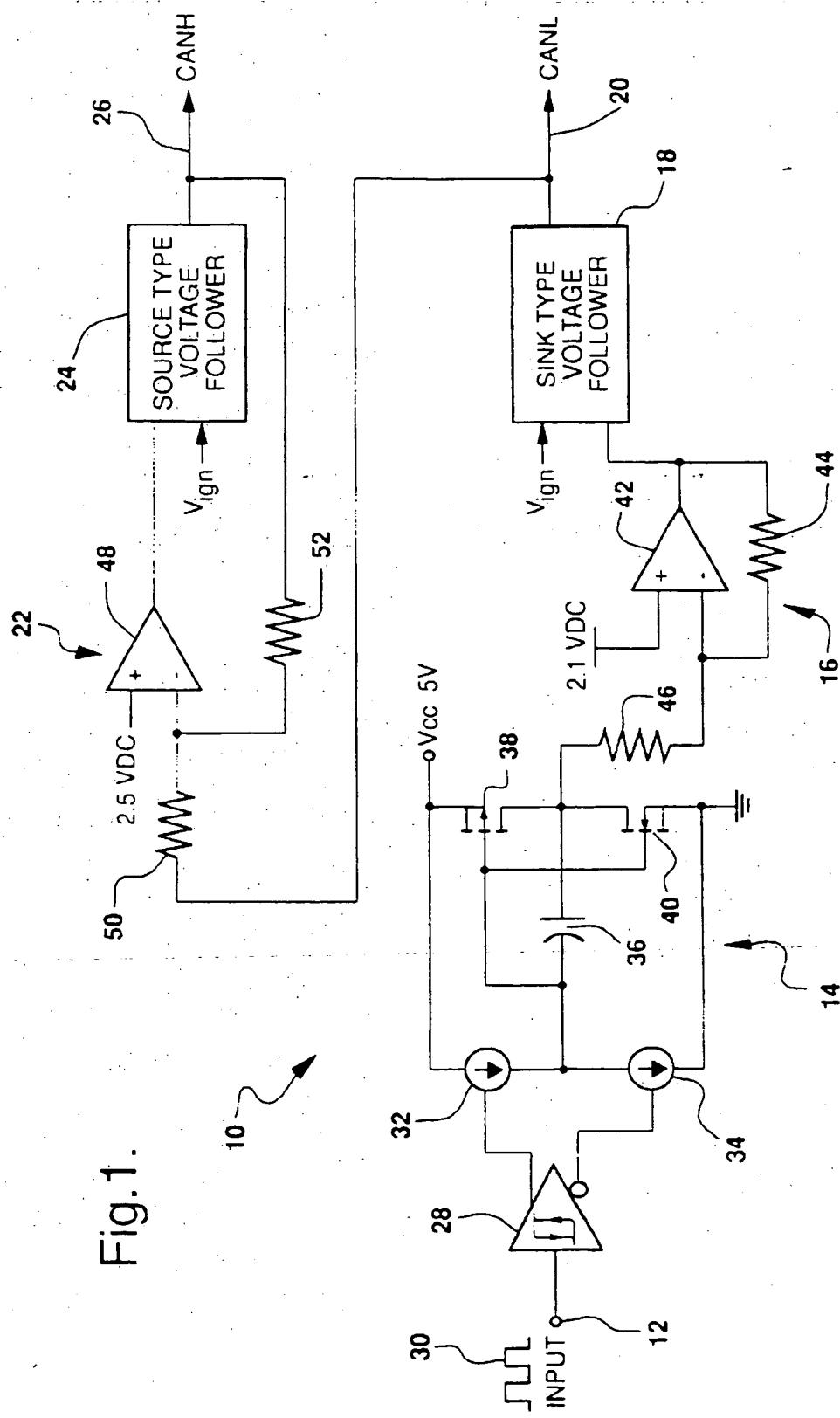


Fig.2A.

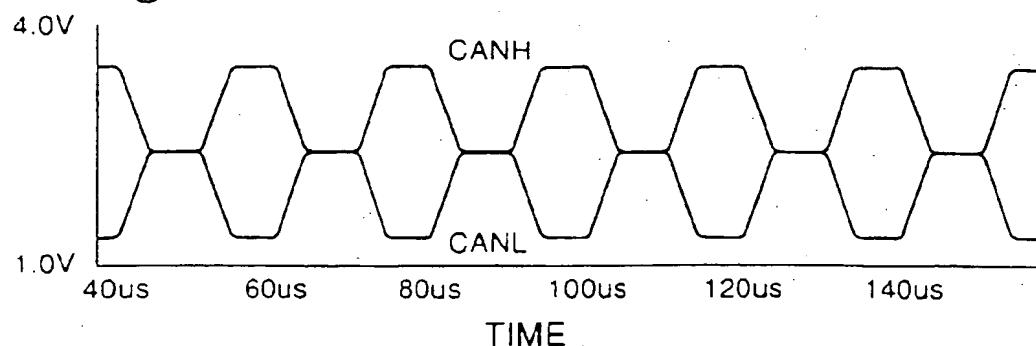


Fig.2B.

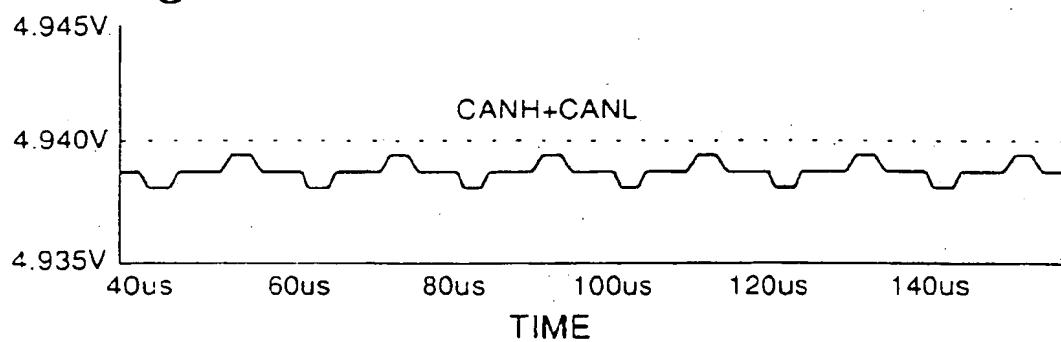


Fig.3.

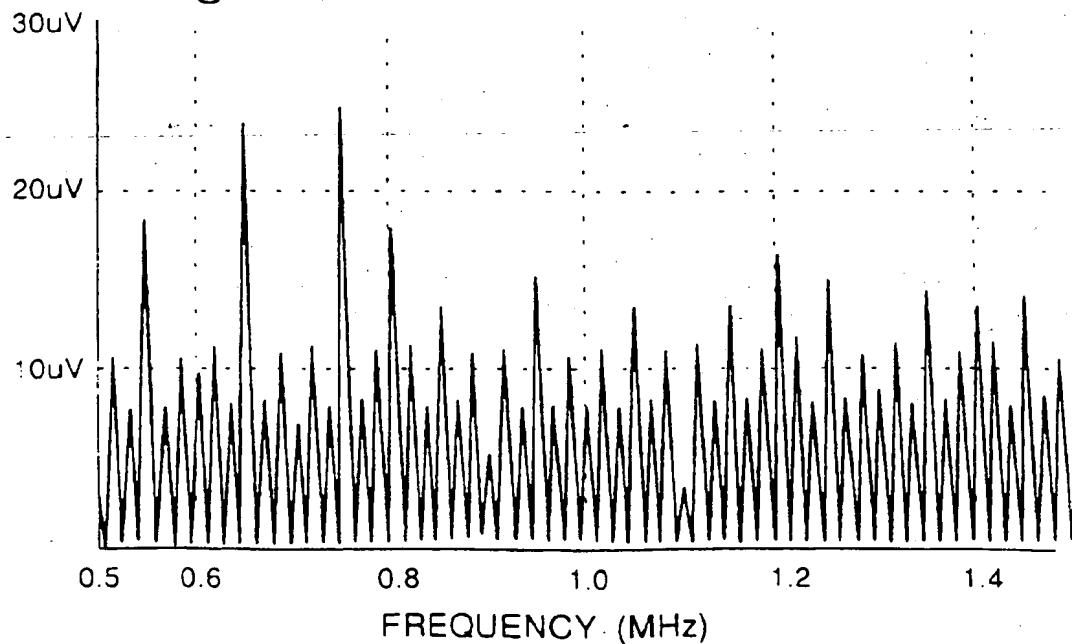


Fig.4A.

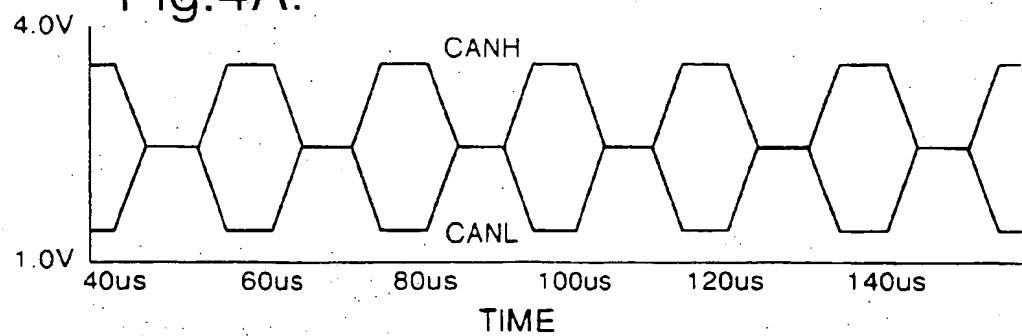


Fig.4B.

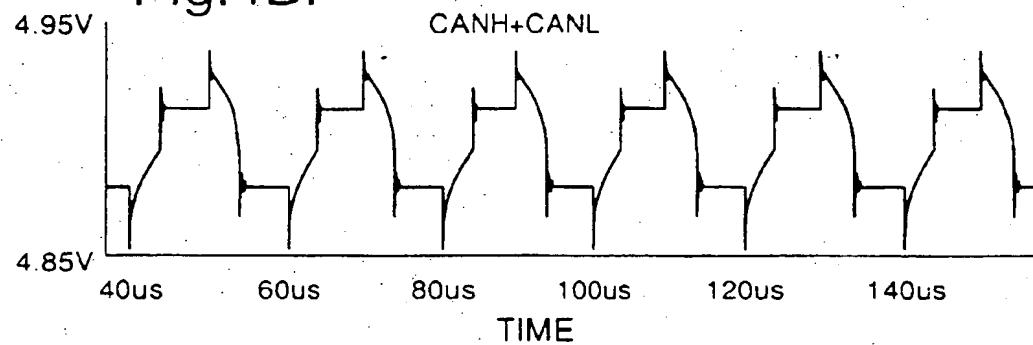


Fig.5.

